ORTEC®

AN34 Experiment 3

Gamma-Ray Spectroscopy Using NaI(Tl)

Equipment Needed from ORTEC

4001A/4002D NIM Bin and Power Supply
905-3 NaI(Tl) Crystal and Photomultiplier Tube Assembly
266 Photomultiplier Tube Base
556 High Voltage Bias Supply
113 Scintillation Preamplifier
575A Spectroscopy Amplifier
3-Z2 Absorber Kit
PbAl-23 Absorber Kit
M-NA-3 NaI Detector Stand
TRUMP-PCI-2K (or TRUMP-2K-32) Plug-In MCA Card (Other ORTEC MCAs may be used)
C-36-12 Cable
C-24-12 Cables (3)
C-24-1 Cables (6)
C-29 (3)

Other Equipment Needed

Oscilloscope
IBM-compatible PC with Windows 98/2000/XP or NT
Gamma Source Kit
^{137}Cs gamma source, 5 µCi ±5%

Additional ORTEC Equipment Needed for Experiment 3.8

427A Delay Amplifier
551 Timing Single-Channel Analyzer
426 Linear Gate
996 Timer & Counter

Purpose

The purpose of this experiment is to acquaint the student with some of the basic techniques used for measuring gamma rays. It is based on the use of a sodium iodide (NaI) detector that is thallium (Tl) activated.

Gamma Emission

Most isotopes used for gamma measurements also have betas in their decay schemes. The typical decay scheme for the isotope will include a beta decay to a particular level followed by gamma emission to the ground state of the final isotope. The beta particles will usually be absorbed in the surrounding material and not enter the scintillator at all. This absorption is normally assured with aluminum absorbers (ref. 10). For this experiment the betas offer no real problem, so absorbers are not specified; there will be some beta absorption by the light shield over the phototube. The gammas, however, are quite penetrating and will easily pass through the aluminum light shield.

Generally there are two unknowns that we would like to investigate about a gamma source. One is the energies of the gammas from the source; the other is the number of gammas that leave the source per unit of time.

In this experiment the student will become familiar with some of the basic NaI (Tl) measurements associated with gamma-emitting unknowns.

A total time of ~6 hours is required to complete all the parts of Experiment 3 (3.1 through 3.10). Since each part is written to be fairly independent of the others, the complete series can be done in two 3-hour lab periods.

EXPERIMENT 3.1

Energy Calibration

Equipment Setup

Set up the elecronics as shown in Fig. 3.1. There are two parameters that ultimately determine the overall gain of the system: the high voltage furnished to the phototube and the gain of the spectroscopy amplifier. The gain of the photomultiplier tube is quite dependent upon its high voltage. A rule of thumb for most phototubes is that a 10%

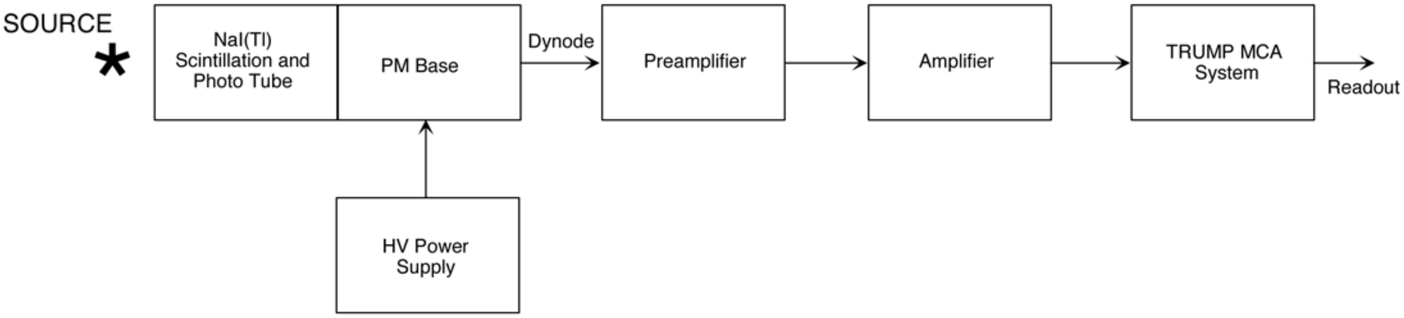

Fig. 3.1. Electronics Block Diagram of Gamma-Ray Spectroscopy System with NaI(Tl) Detector.

change in the high voltage will change the gain by a factor of 2. The high voltage value depends on the phototube being used. Consult your instruction manual for the phototube and select a value in the middle of its normal operating range. (The instructor may wish to recommend a value).

Set the indicated modules as follows:

556 High Voltage: See phototube instructions and set the level at about the middle of the acceptable operating range (normally about +1000 V).

113 Scintillation Preamplifier: Set the Input Capacitance switch at 200 pF. The output pulses will be positive.

575A Amplifier: Positive input and Bipolar output. Shaping time set to 0.5 µsec. The gain will be adjusted during the experiment.

Multichannel Analyzer: PHA Analysis mode; 1024 channels are adequate for this experiment.

Procedure

1. Place the ^{137}Cs source from the gamma source kit (Eγ = 0.662 MeV) ~2 cm in front of the NaI (Tl) crystal.

2. Adjust the coarse and fine gain controls of the 575A Amplifier so that the 0.662 MeV photopeak for ^{137}Cs falls at approximately channel 280. For the illustrations shown in Figs. 3.2 and 3.3, the gain of the system has been set so that 1 MeV falls at about channel 420 to 425. Since the system is linear, 2 MeV would therefore fall at approximately channel 840 to 850.

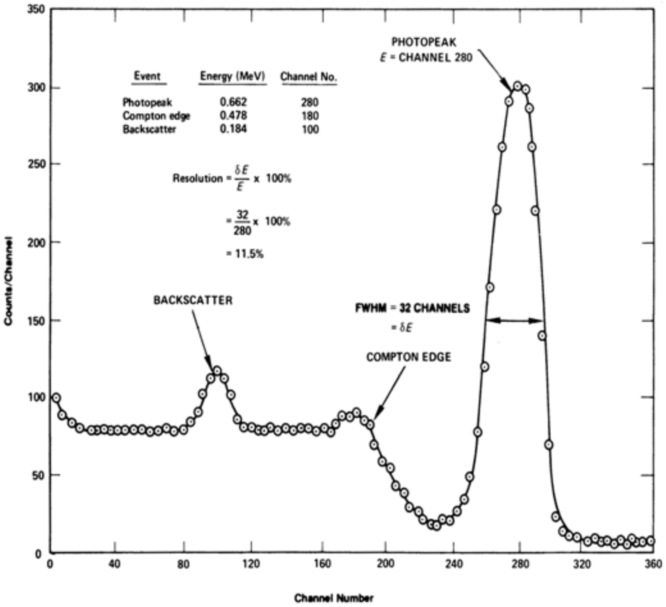

Fig. 3.2. NaI(Tl) Spectrum for ^{137}Cs.

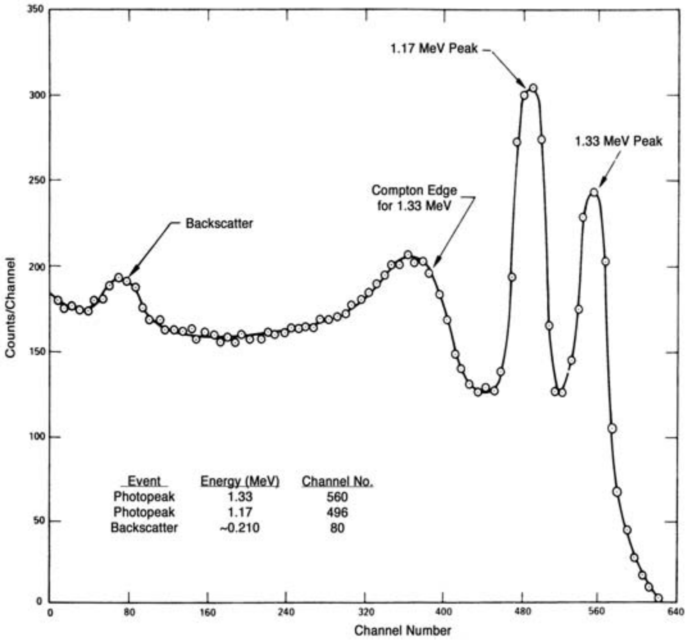

Fig. 3.3. NaI)Tl) Spectrum for ^{60}Co.

3. Accumulate the ^{137}Cs spectrum for a time period long enough to determine the peak position. Fig. 3.2 shows a typical ^{137}Cs spectrum that has been plotted. Although these spectra are usually plotted on semilog graph paper, the figures shown in this experiment are plotted on linear paper to point out some of the features of the spectra.

4. After the ^{137}Cs spectrum has been read from the MCA, erase it and replace the ^{137}Cs source with a ^{60}Co source from the gamma source kit.

5. Accumulate the spectrum for a period of time long enough for the spectrum to be similar to that in Fig. 3.3.

6. Read out the MCA.

EXERCISES

a. Plot both the ^{137}Cs and ^{60}Co spectra and fill in items 1, 2, and 3 in Table 3.1.

b. From items 1, 2, and 3 in Table 3.1, make a plot of energy of the photopeaks vs. channel number. Fig. 3.4 shows this calibration for the data taken from Figs. 3.2 and 3.3. If other calibration sources are available, additional data points can be added to Fig. 3.4. The other entries in Table 3.1 will be filled out in Experiment 3.3.

c. Use the energy calibration feature of the MCA and compare the results with those found in Exercise b.

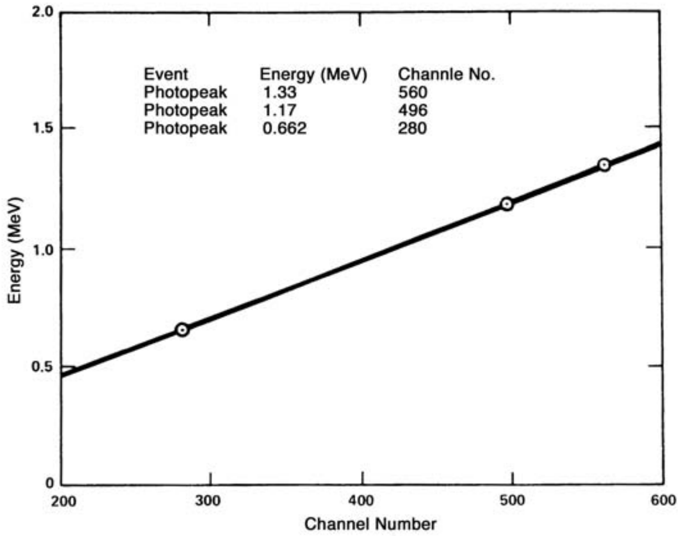

Fig. 3.4. Energy Calibration Curve for NaI(Tl) Detector.

Table 3.1

	Event	Energy (MeV)	Channel No.
1.	0.662-MeV photopeak	0.662	
2.	1.17-MeV photopeak	1.17	
3.	1.33-MeV photopeak	1.33	
4.	Compton edge ^{137}Cs		
5.	Backscatter ^{137}Cs		
6.	Backscatter ^{60}Co		

EXPERIMENT 3.2

Energy Analysis of an Unknown Gamma Source

Purpose

The purpose here is to use the calibrated system of Experiment 3.1 to measure the photopeak energies of an unknown gamma emitter and to identify the unknown isotope.

Procedure

1. Erase the ^{60}Co spectrum from the MCA, but do not change any of the gain calibration settings of the system

2. Obtain an unknown gamma source from the instructor. Accumulate a spectrum for the unknown source for a period of time long enough to clearly identify its photopeak(s). From the calibration curve, determine the energy for each photopeak.

EXERCISE

Use refs. 7 and 8 to identify the unknown isotope.

EXPERIMENT 3.3

Spectrum Analysis of ^{60}Co and ^{137}Cs

Purpose

The purpose of this experiment is to explain some of the features, other than the photopeaks, usually present in a pulse-height spectrum. These are the Compton edge and the backscatter peak.

The Compton interaction is a pure kinematic collision between a gamma photon and what might be termed a free electron in the NaI (Tl) crystal. By this process the incident gamma gives up only part of its energy to the electron. The amount given to the recoil electron (and the intensity of the light flash) depends on whether the collision is head-on or glancing. For a head-on collision the gamma imparts the maximum allowable energy for the Compton interaction. The energy of the scattered gamma can be determined by solving the energy and momentum equations for this billiard ball collision. The solution for these equations in terms of the scattered gamma can be written approximately as

$$E\gamma' \cong \frac{E\gamma}{1 + 2E\gamma\,(1-\cos\theta)'} \qquad (1)$$

where

$E\gamma'$ = energy of the scattered gamma in MeV,

θ = the scattered angle for γ',

$E\gamma$ (= the incident gamma energy in MeV.

If $\theta = 180°$ due to a head-on collision in which γ' is scattered directly back, Eq. (1) becomes

$$E\gamma' \cong \frac{E\gamma}{1 + 4E\gamma} \qquad (2)$$

As an example, we will calculate $E\gamma'$ for an incident gamma energy of 1 MeV:

$$E\gamma' \cong \frac{1\ \text{MeV}}{1 + 4} = 0.20\ \text{MeV} \qquad (3)$$

The energy of the recoil electron, E_e, for this collision would be 0.80 MeV. This is true since

$$E_e = E\gamma - E\gamma' \qquad (4)$$

Then the position of the Compton edge, which is the maximum energy that can be imparted to an electron by the Compton interaction, can be calculated by Eq. (4).

EXERCISES

a. Calculate the energy of the Compton edge for the 0.662 MeV gammas from ^{137}Cs. Enter this value in Table 3.1. From your plot and calibration curve, does this calculation agree with your measured value?

b. Backscatter occurs when gammas make Compton interactions in the material that surrounds the detector. Fig. 3.5, taken from ref. 10, is a good illustration of the various events that can occur in a typical source–NaI(Tl)–lead shield arrangement. Backscattered gammas from these interactions ($E\gamma'$) create photoelectric interactions in the NaI (Tl) when they enter the crystal. The energy of the backscattered peak can be found by solving Eq. (2).

c. Solve Eq. (2) for the background gammas from ^{137}Cs and for the 1.33 MeV gammas from ^{60}Co. Fill in the rest of Table 3.1. How do your measured energies compare with the theoretical energies from Eq. (2)? If the backscatter peak is not very pronounced in your spectrum, it can be improved by accumulating a spectrum with a sheet of lead absorber placed slightly to the left of the source in Fig. 3.1.

EXPERIMENT 3.4

Energy Resolution

Purpose

The resolution of a spectrometer is a measure of its ability to resolve two peaks that are fairly close together in energy. Fig. 3.2 shows the gamma spectrum that was plotted for the ^{137}Cs source. The resolution of the photopeak is found by solving the following equation:

$$R = \frac{\delta E}{E} \times 100 \qquad (5)$$

where

R = the resolution in percent,

δE = the full width of the peak at half of the maximum count level (FWHM) measured in number of channels,

E = the channel number at the centroid of the photopeak.

In Fig. 3.2 the photopeak is in channel 280 and its FWHM = 32 channels. From Eq. (5) the resolution is calculated to be 11.5%.

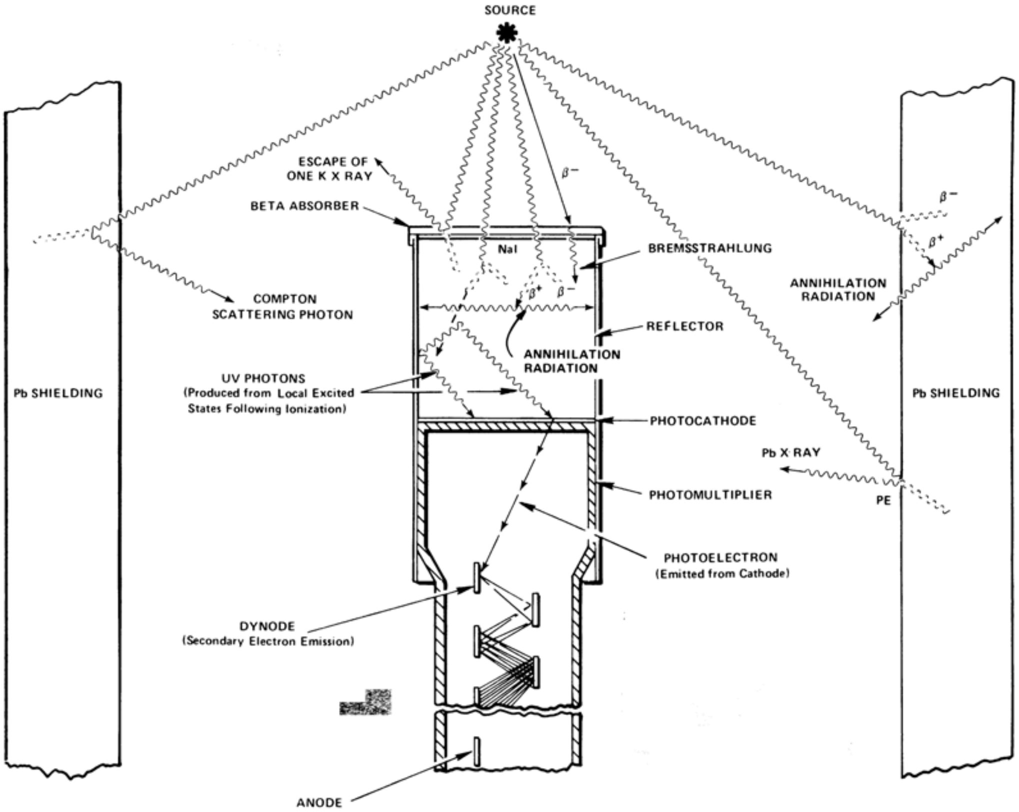

Fig. 3.5. Various Events in the Vicinity of a Typical Source/Crystal Detector/Shield Configuration.

EXERCISE

Calculate the resolution of the system from your ^{137}Cs spectrum. Record this value for later reference.

EXPERIMENT 3.5

Acivity of a Gamma Emitter (Relative Method)

Purpose

In Experiments 3.1 and 3.3, procedures were given for determining the energy of an unknown gamma source. Another unknown associated with the gamma source is the activity of the source, which is usually measured in curies (Ci); 1 Ci = 3.7 x 10^{10} disintegrations/second. Most of the sources used in nuclear experiments have activities of the order of microcuries (µCi). The purpose of this experiment is to outline one procedure, called the relative method, by which the activity of a source can be determined.

In using the relative method, it is assumed that the unknown source has already been identified from its gamma energies. For this example, assume that the source has been found to be ^{137}Cs. Then all that is necessary is to compare the activity of the unknown source to the activity of a standard ^{137}Cs source that will be supplied by the laboratory instructor.

For convenience, call the standard source S1 and the unknown source U1.

Procedure

1. Place source S1 ~ 4 cm from the face of the NaI(Tl) detector (or closer if necessary to get reasonable statistics) and accumulate a spectrum for a period of live time, selectable on the MCA, long enough to produce a spectrum similar to Fig. 3.2.

2. Use the cursor to determine the sum under the photopeak. In the example shown in Fig. 3.2, this would correspond to adding up all counts in channels 240 through 320. Define this sum to be Σ_{S1}.

3. Clear (erase) the MCA spectrum. Remove source S1 and replace it with source U1, positioned exactly the same distance from the crystal as S1 was. Accumulate a spectrum for the same period of live time that was used in step 1. Sum the peak as in step 2.

4. Clear the spectrum from the MCA. Remove source U1 and accumulate background counts for the same period of live time that was used in steps 1 and 3 above.

5. Sum the background counts in the same channels that were used for the photopeaks in steps 1 and 2 above. Call the sum Σ_b.

EXERCISE

Solve for the activity of U1 by using the following ratio:

$$\frac{\text{activity of U1}}{\text{activity of S1}} = \frac{\Sigma_{U1} - \Sigma_b}{\Sigma_{S1} - \Sigma_b} \qquad (6)$$

Since the efficiency of the detector is only energy dependent, the standard and unknown sources do not have to be the same isotope. It is necessary only that their gamma energies be approximately the same (±10%) in order to get a fairly good estimate of the absolute gamma activity of the unknown.

EXPERIMENT 3.6

Activity of a Gamma Emitter (Absolute Method)

Purpose

The activity of the standard used in Experiment 3.5 can be determined by the absolute method. The purpose of this experiment is to outline the procedure for this method. Here the source to be measured will be called U1.

Procedure

1. Place source U1 9.3 cm away from the face of the detector.

2. Accumulate a spectrum and note the live time that is used.

3. Use the cursor to determine the sum under the photopeak, Σ_{U1}. Then clear the spectrum, remove the source, accumulate background for the same live time, and calculate Σ_b.

4. Use the following formula to calculate the activity of U1:

$$\text{activity of U1} = \left(\frac{\Sigma_{U1} - \Sigma_b}{t}\right)\frac{1}{G\varepsilon_p f} \qquad (7)$$

where

t = live time in seconds,

ε_p = intrinsic peak efficiency for the gamma energy and detector size used (Fig. 3.6 and ref. 10),

f = the decay fraction of the unknown activity which is the fraction of the total disintegrations in which the measured gamma is emitted (refs. 7 and 8 and Table 3.2)

G = area of the detector (cm^2)/4πs^2,

s = source-to-detector distance in cm.

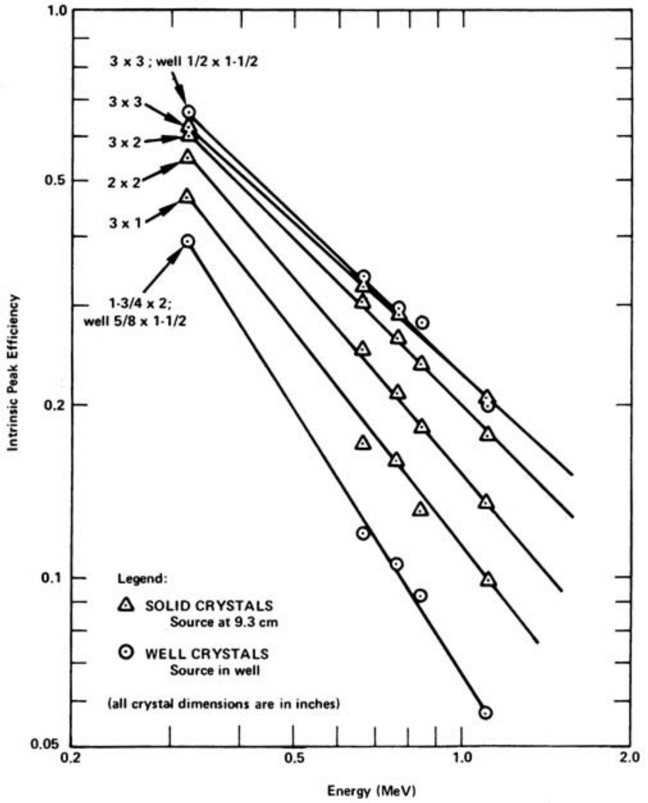

Fig. 3.6. Intrinsic Peak Efficiency of Various NaI(Tl) Crystals vs Gamma energy.

Table. 3.2. Gamma Decay Fraction, (f), for Some Common Isotopes.

Isotope	Gamma Energy (MeV)	f
137Cs	0.662	0.92
51Cr	0.323	0.09
60Co	1.17	0.99
60Co	1.33	0.99
22Na	1.276	0.99
22Na	0.511	0.99
54Mn	0.842	1.00
65Zn	1.14	0.44

EXPERIMENT 3.7

Mass Absorption Coefficient

Purpose

The purpose of this experiment is to measure experimentally the mass absorption coefficient in lead for 662 keV gamma rays.

References 2, 3, and 5 point out that gammas interact in matter primarily by photoelectric, Compton, or pair-production interactions. The total-mass absorption coefficient can be easily measured with a gamma-ray spectrometer. In this experiment we will measure the number of gammas that are removed from the photopeak by photoelectric or Compton interactions that occur in a lead absorber placed between the source and the phototube.

From Lambert's law (ref. 1), the decrease in intensity of radiation as it passes through an absorber is given by

$$I = I_o e^{-\mu x} \qquad (8)$$

where

I = intensity after the absorber,

I_0 = intensity before the absorber,

μ = total-mass absorption coefficient in cm^2/g,

x = density thickness in g/cm^2.

The density thickness is the product of the density in g/cm^3 times the thickness in cm.

The half-value layer (HVL) is defined as the density thickness of the absorbing material that will reduce the original intensity by one-half. From Eq. (8):

$$\text{In}\ I/I_o = -\mu x \qquad (9)$$

If $I/I_0 = 0.5$ and x = HVL, $\text{In}\ 0.5 = -\mu(\text{HVL})$ and hence

$$\text{HVL} = \frac{0.693}{\mu} \qquad (10)$$

In this experiment we will measure μ in lead for the 662 keV gammas from^{137}Cs. The accepted value is 0.105 cm^2/g. Values for other materials can be found in ref. 8.

Procedure

1. Place the ^{137}Cs source about 5.0 cm from the NaI(Tl) detector and accumulate the spectrum long enough for the sum under the 662 KeV peak ($\Sigma_{Cs}-\Sigma_b$) to be at least 6000 counts. Determine ($\Sigma_{Cs}-\Sigma_b$).

2. Clear the MCA and insert a piece of lead from the absorber kit between the source and the detector. Accumulate the spectrum for the same period of live time as in step 1 above. Determine (3Cs - 3b).

3. Clear the MCA and insert another piece of lead. Determine (Σ_{Cs}–Σ_{b}).

4. Repeat with additional thicknesses of lead until the count-sum is >1000. Fill in the data in Table 3.3.

Table. 3.3. Data for Mass Absorption Coefficient.

Absorber	Absorber Thickness (mg/cm^2)	$\Sigma_{Cs} - \Sigma_{b}$
1	0	
2		
3		
4		
5		
6		
7		

EXERCISES

a. Using semilog graph paper, plot I vs. absorber thickness in mg/cm^2, where I = (Σ_{Cs}–Σ_{b})/live time. Determine the HVL from this curve and calculate µ from Eq. (10). How does your value compare with the accepted value of 0.105 cm^2/g?

b. Repeat the above experiment with the aluminum absorbers in the absorber kit. The µ for aluminum is 0.074 cm^2/g.

EXPERIMENT 3.8

The Linear Gate in Gamma-Ray Spectroscopy

Purpose

The purpose of this experiment is to show how a linear gate can be used with an MCA in gamma-ray spectroscopy. The linear gate will limit the analysis of input pulse amplitudes to those that will be included within the photopeak.

The measurement of the mass absorption coefficient in Experiment 3.7 required the accumulation of several complete spectra, although the data of interest were included within only a fraction of the total number of channels that were used. The normal time for completeing Experiment 3.7 is approximately 45 minutes. By using the linear gate, the same information can be obtained in about one-third the time. An equivalent saving of time can also be made in Experiments 3.5 and 3.6 (Source Activity Determinations). Since the procedures are about the same as for Experiment 3.7, the student should repeat these experiments with the linear gate to see how much time will be saved.

See the list at the beginning of Experiment 3 for the additional equipment required for Experiment 3.8.

Connect the system components as shown in Fig. 3.7. Connect the bipolar output of the 575A Amplifier to both the 427A Delay Amplifier and the 551 Timing Single-Channel Analyzer. Connect the Delay output to the Linear Input of the 426 Linear Gate and connect the Gate output to the analyzer input. Connect the SCA output to both the 996 Counter input and the Enable input of the 426 Linear Gate.

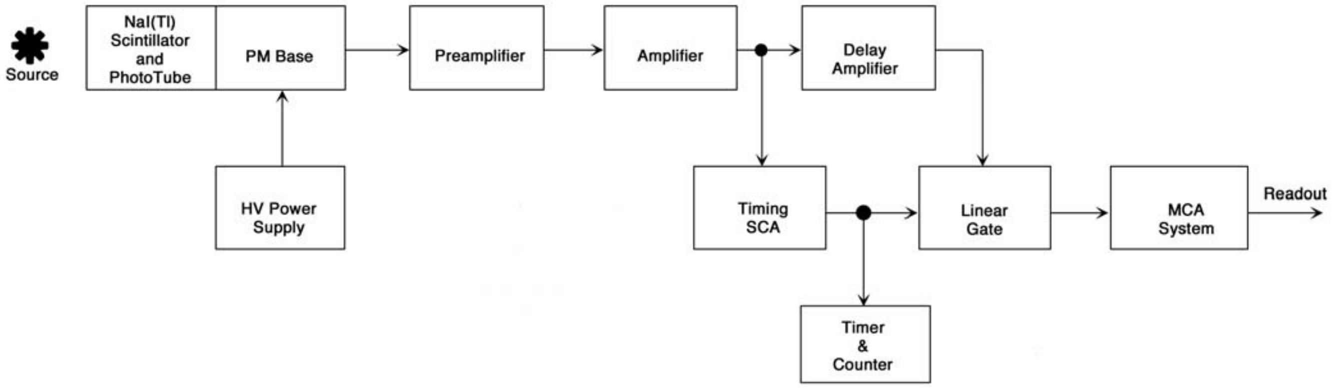

Fig. 3.7. Block Diagram of Electronics for Gamma-Ray Spectrometry System with a Linear Gate.

The 426 Linear Gate is a module that permits linear pulses to be passed only during the time interval that follows each Enable input. In normal operation the adjusted time interval will allow only one linear pulse to be fed into the MCA.

The Timing Single-Channel Analyzer determines whether each input pulse amplitude is within the window and generates a logic output pulse for each input pulse that satisfies the criteria. By adjusting the lower and upper levels of its window, the 551 can determine what portion of the spectrum is gated through for analysis in the MCA. This is true since it delivers the enable logic pulse to open the linear gate.

From the standpoint of timing, one would like to have the logic pulse arrive at the enable input of the linear gate just prior to the arrival of the corresponding linear pulse that is to be gated. Since the amplifier provides a bipolar output to the SCA, and since the SCA generates an output at 50% of full amplitude on the trailing edge of the positive lobe, the SCA output will occur at about 2 µs after the onset of the pulse. Thus, if the 427A Delay Amplifier is set for 3 µs and the 426 Linear Gate width is adjusted to its 4 µs maximum, the gate passes the input pulse for a period from 1 µs before the delayed pulse reaches the 426 until 3 µs of elapsed pulse time. This passes the positive portion of the bipolar pulse, which is all that affects the MCA measurement. The negative portion of the bipolar pulse is not used.

The inclusion of a counter in Fig. 3.7 permits a direct total of the counts to be observed, and the adjustment of the window width will limit these to the peak area. This simplifies the summing of counts for peak area integrations.

Fig. 3.8 shows how Fig. 3.2 might look if the window of the SCA were set properly to just span the ^{137}Cs photopeak. Since the MCA has a live display while it is accumulating, it is quite simple to properly adjust the widow of the SCA.

The single-channel principle and control of the linear gate are examined here with individual modules. Both functions are also included in the MCA, so the separate modules are not required for other experimental applications.

Module Settings

Use the same settings for the high-voltage power supply, preamplifier, and amplifier that were used for Experiment 3.1. Set the 426 linear Gate for Normal with its Gate Width control fully clockwise for 4 µs. Set the 996 Timer for ~30 minutes, and the Counter for count. Use the Positive input from one of the Pos Out connectors on the 551 Timing SCA; reset the 996 Counter to zero. Set the 551 for Normal operation, the Lower-Level control at 030, the Upper-Level control fully cockwise at 1000 divisions, and Delay at minimum for 0.1 µs. Set the 427A Delay Amplifier for a 3 µs delay.

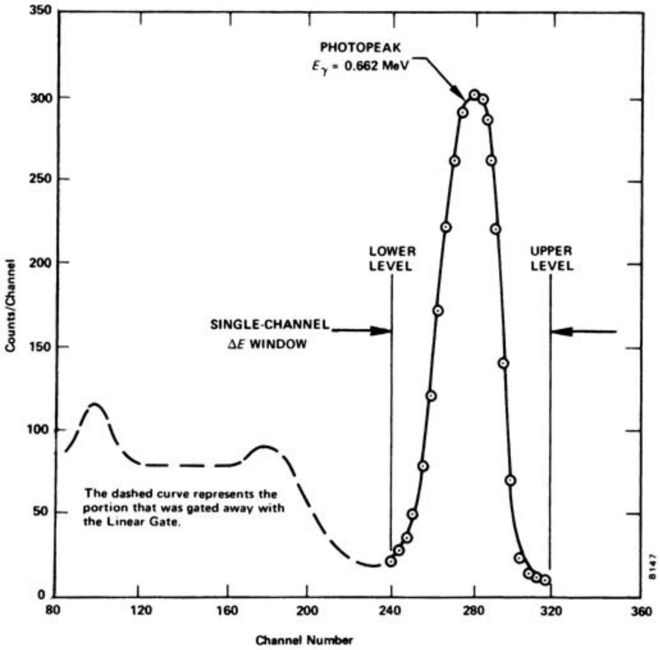

Fig. 3.8. ^{137}Cs Spectrum with the Linear Gate.

Procedure

1. Place the ^{137}Cs source about 4 or 5 cm from the crystal face. Accumulate a spectrum in the MCA while adjusting the E and ∆E window on the 551 Timing SCA. Set the window so that it just brackets the photopeak as in Fig. 3.8. You are now ready to make the first measurements.

2. Clear the MCA and reset the counter to zero. Start both at the same time and accumulate for a period of time long enough to obtain about 6000 counts in the counter. Record the total elapsed time for the measurement, the average dead time from the MCA, and the count in the counter. Read out the analyzer and then clear both the MCA and the counter.

3. Place the first lead absorber between the source and the detector as in Experiment 3.7 and accumulate for the same period of time that was used in step 2 above. Record only the counter counts and the total elapsed time. It is not necessary to read out the MCA for each spectrum since the counter is summing the counts under

Table. 3.4.

Absorber	Absorber Thickness (mg/cm^2)	$\Sigma_{Cs} - \Sigma_b$
1	0	
2		
3		
4		
5		
6		
7		

the photopeak. You should observe the MCA for each spectrum to make sure that the proper spectrum is being stored.

4. Repeat step 3 for each added absorber thickness that was used in Experiment 3.7. Make a background run with the source removed, and fill in Table 3.4 as in Experiment 3.7.

5. Calculate the same data as in Experiment 3.7, Exercises a and b.

6. In step 2 the output of the MCA was read. Sum this output spectrum and compare it with the counter sum that was taken from the same run. The counter sum should be slightly larger since it does not suffer from dead-time corrections at these counting rates. The MCA does suffer, because it requires some amount of time to measure and store each pulse and thus does not actually analyze as many pulses as have been furnished to it. The MCA sum should be equal to the counter count times the percent of live time, which is equal to the live time of the MCA divided by the clock time for the spectrum accumulation.

EXPERIMENT 3.9

Sum Peak Analysis

Fig. 3.3 shows the two pronounced peaks in ^{60}Co. Fig. 3.9 shows the decay scheme of ^{60}Co.

Most of the time the decay occurs by β emission to the 2.507 MeV excited state of ^{60}Ni. Subsequent decay to the ground state always occurs by gamma emission to the 1.3325 MeV level (a 1.174 MeV gamma) followed almost simultaneously by the 1.3325 MeV gamma to the ground state. In Experiment 19 we will show that these two events are in coincidence and have an angular correlation that deviates from an isotopic distribution by only 16%. For the purposes of this experiment we can assume that each of these gammas are isotopically distributed. In other words, if γ_1 goes in a particular direction, γ_2 can go in any of the 4π steradians that it wishes. There is a certain probability that it will go in the same direction as γ_1. If this occurs within the resolving time of the detector, γ_1 and γ_2 will be summed, and hence a summed peak will show up in the spectrum. From the definitions in Experiment 3.6, the number of counts, Σ_1, under the γ_1 peak is given by:

$$\Sigma_1 = \varepsilon_1 G f_1 t A \tag{11}$$

where A is the activity of the sample and t is the time. In a similar calculation, the sum Σ_2 for γ_2 is given by:

$$\Sigma_2 = \varepsilon_1 G f_2 t A \tag{12}$$

From Eqs. (11) and (12) the number of counts in the sum peak, Σ_s is given by:

$$\Sigma_s = \varepsilon_1 \varepsilon_2 f_1 f_2 G^2 At\,[W(0°)] \tag{13}$$

where W(0°) is a term that accounts for the angular correlation function. For the case of ^{60}Co, Eq. (13) is quite simple. Σ_S becomes:

$$(\Sigma_s)_{^{60}Co} \cong \varepsilon_1 \varepsilon_2 G^2 At \tag{14}$$

since W(0°) $\cong$ 1.0.

In this experiment, we will show that the sum peak for ^{60}Co has an energy of 2.507 MeV, and that its sum is given by Eq. (14).

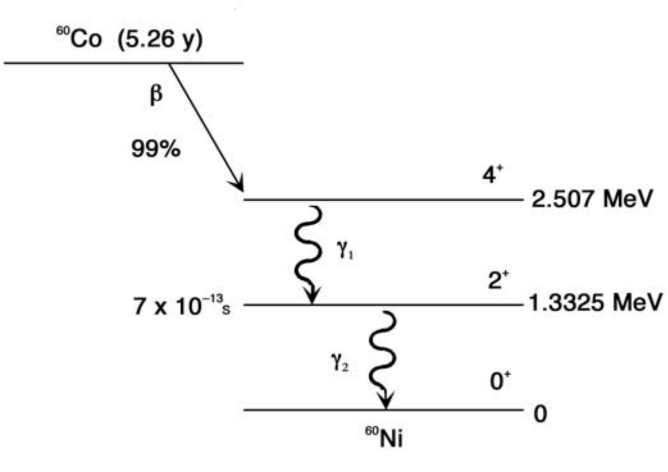

Fig. 3.9. The Decay Scheme of ^{60}Co.

Procedure

1. Set up the electronics as shown in Fig. 3.1

2. Use the gamma sources from the gamma source kit to calibrate the MCA so that full scale is ~3.0 MeV. For 1024 channels this would put the ^{137}Cs (0.662 MeV) peak at approximately channel 225.

3. Construct a calibration curve as in Experiment 3.1.

4. Place the ^{60}Co source from the source kit at exactly 9.3 cm from the face of the detector. Count for a period of time long enough so that the area under the sum peak is ~1000 counts. This procedure was outlined in Experiment 3.6.

EXERCISES

a. Verify that the energy of the sum peak is 2.507 MeV. Subtract the background from the sum peak and verify its sum from Eq. (14).

b. Repeat this sum peak analysis for the ^{22}Na source. Fig. 3.10 shows the decay scheme for ^{22}Na and a typical spectrum with the sum peak.

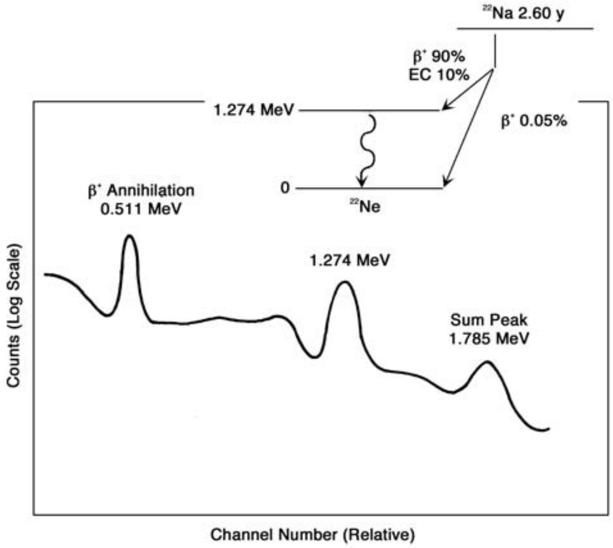

Fig. 3.10. Sum Peak for the 22Na Source from Source Kit SK-1G.

EXPERIMENT 3.10
Photoelectric Absorption

Purpose

The purpose of this experiment is to study the photoelectric absorption of photons and verify the strong dependence of this process on the atomic number of the absorbing material.

When a gamma of energy <150 keV interacts with matter, the interaction has a high probability of being photoelectric. In the photoelectric interaction, the photon interacts with one of the tightly bound electrons in the material. The electron, in general, is knocked out of the atom with an energy given by:

$$E_e = hf - E_b$$

where f is the frequency of the photon and E_b is the binding energy of the electron that is involved in the interaction. The probability of photoelectric interaction is dependent on the atomic number of the absorbing material and the energy of the gamma or x-ray photon. Although it is difficult to write out an exact analytic expression for this probability, it can be shown that, for low-energy photons

$$\mu = \frac{K \bullet Z^n}{E\gamma^3} \qquad (15)$$

where K is a constant, Z is the atomic number, and n is usually between 4 and 5.

Procedure

The setup for this experiment is the same as for Experiment 3.7.

1. Place the ^{57}Co source ~3.8 cm from the NaI(Tl) detector. Accumulate for a time period long enough to get reasonable statistics in the 122 KeV peak. As in Experiment 3.7, $\Sigma - \Sigma_b$ should be at least 6000 counts.

2. Clear the MCA and place the thinnest aluminum absorber from Absorber Kit 3-Z2 between the source and the detector. Count for the same period of time as in step 1. Repeat for the other two aluminum absorbers.

3. Repeat steps 1 and 2 for the other thin absorbers, Fe, Cu, Mo, Sn, Ta, and Pb in the Absorber Kit. Note: the counting time might have to be increased as the atomic number of the absorber is increased.

EXERCISES

a. For the three measurements made with the thin alumunum foils, calculate and average μ, Eq. (9). Repeat for the other absorbers.

b. Make a plot of μ vs. $Z^{4.5}/E_\gamma^3$ from your experimental data. How do your results compare to the theory?

References

1. G. F. Knoll, Radiation Detection and Measurement, John Wiiley and Sons, New York (1979).

2. J. B. Birks, The theory and Practice of Scintilation Counting, Pergammon Press, Oxford (1964).

3. S. M. Shafroth, Ed., Scintillation Spectroscopy of Gamma Radiation, Gordon and Breach, London (1967).

4. K. Siegbahn, Ed., Alpha, Beta and Gamma Spectroscopy, North Holland Publishing Co., Amsterdam (1968).

5. P. Quittner, Gamma Ray Spectroscopy, Halsted Press, New York (1972).

6. W. Mann and S. Garfinkel, Radioactivity and its Measurement, Van Nostrand-Reinhold, New York (1966).

7. C. M. Lederer and V. S., Shirley, Eds., Table of Isotopes, 7th Edition, John Wiley and Sons, Inc., New York (1978).

8. Radiological Health Handbook, U.S. Dept. of Health, Education,and Welfare, PHS Publ. 2016. Avaialble from National Technical Information Service, U.S. Dept. Of Commerce, Springfield, Virginia.

9. 14th Scintillation and Semiconductor Counter Symposium, IEEE Trans. Nucl. Sci. NS-22(1) (1975).

10. R. L. Heath, Scintillation Spectrometry, Gamma-Ray Spectrum Catalog, 1 and 2, Report No. IDO-16880. Available from the National Technical Information Center, U. S. Dept. of Commerce, Springfield, Virginia.